

## A comparison of results obtained with two methods for assessing yield stability

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**Summary.** A major objective of the CIMMYT Maize Program is to develop open-pollinated varieties of maize (*Zea mays* L.) that are well adapted to a wide range of environments. To achieve this breeding goal, it is essential that the program use a stability technique that will identify high-yielding, stable genotypes accurately in international trials conducted under different environmental conditions. The objective of this study was to compare a spatial method with a modified conventional regression analysis method to determine the yield stability of 27 CIMMYT maize varieties evaluated at 37 locations. The methods also were compared on the basis of their consistency in assessing the stability of varieties when certain locations were omitted, and when subsets of varieties were analyzed. The varieties found to be stable by the spatial method with all sites included in the analysis were also stable (1) when the lowest and highest yielding sites were excluded from the analyses, and (2) when the varieties were considered, along with others, as a subset of the original group of materials. Stability parameters determined by regression analysis, however, varied for some varieties when (1) extreme sites were excluded, and (2) a subset of entries was considered in isolation. Because the spatial method was more consistent in identifying high-yielding stable varieties, it was considered the more useful of the two methods.

**Key words:** *Zea mays* L. – Selection – Regression analysis – Principal coordinates analysis

### Introduction

The amount of progress made in selecting and improving genotypes is affected by the complex phenom-

enon of genotype-environment interaction. The difficulty in describing that interaction in terms of genotype stability over different environments has been recognized.

The more widely-used method for detecting stable genotypes is the regression approach (Yates and Cochran 1938; Finlay and Wilkinson 1963; Eberhart and Russell 1966), however, various researchers have pointed out some limitations of this technique (Knight 1970; Freeman and Perkins 1971; Witcombe and Whittington 1971; Hill 1975; Baker 1969; Byth et al. 1976). One of the problems with regressing genotype means on environmental indices arises when extreme points are considered (Westcott 1986; Hill and Baylor 1983). If only a few extreme points are included in the analysis, regression coefficients can vary substantially from the results obtained without those points. Another problem with the regression of yield on environments is that stability parameters depend on the particular set of genotypes included (Knight 1970; Lin et al. 1986; Mead et al. 1986). Thus, stability parameters determined for a given entry will vary according to the mean performance of the genotypes with which the entry is compared.

Multivariate methods have also been used in analysing stability in plant breeding and have been particularly appropriate for analyzing a genotype-by-environment data matrix where G genotypes tested in E environments can be regarded as G points in an E-dimensional space (Lin et al. 1986; Gauch 1985). Principal coordinate analysis was developed to reduce the high-dimensionality of the raw data and obtain a geometrical configuration of points in a low-dimensional space without distorting the original relationship between items (Gower 1966).

The Maize Program of the International Maize and Wheat Improvement Center (CIMMYT) develops open-pollinated maize varieties from broad-based gene pools and populations and disseminates this germplasm primarily to developing countries (Havener 1983). A major goal of the maize program is that the varieties perform well in a wide range of environments, so breeders must place as much emphasis on yield stability and broad adaptation as on achievement of maximum yields. Therefore, accurate assessment of genotype stability is important to the program.

This study was conducted to compare the results of two methods of assessing yield stability. A modified regression analysis method (Verma et al. 1978) was compared with a recently developed spatial method (Westcott 1987) in terms of: (1) the ability to detect stable varieties, (2) robustness when extremely high- or low-yielding environments are excluded from the analysis, and (3) reliability when stability estimates are based on a subset of genotypes.

### Materials and methods

Stability of grain yield ( $\text{Mg ha}^{-1}$ ) was analyzed for an experimental variety trial (EVT), in which 27 varieties were tested at 37 locations during 1980. The trial had a randomized complete block design with four replications at each location. Entries were formed on the basis of results from the international progeny testing trials (IPTTs), in which full-sib families of CIMMYT populations were tested (Johnson 1974; Vasal et al. 1982). Each variety was developed by recombining the ten highest-yielding full-sib families and was designated by the name of the IPTT test site, the test year, and the population number (Table 1). Poza Rica 7921, for example, was developed on the basis of results from an IPTT of population 21 conducted at Poza Rica, Mexico, during 1979. An "across" variety was created from the ten families which performed best across all six sites where the IPTT was grown.

#### Modified regression analysis method

As suggested by Verma et al. (1978), environments were subdivided into two major groups: one set of sites with negative environmental indices and the other with positive environmental indices. Eberhart and Russell (1966) stability parameters were calculated for each genotype in each subgroup. Genotypes were then classified based on their regression coefficients in the two sets of environments; the combination of regression coefficients that indicate the best genotypes for poor environments, favorable environments, or both are listed in Table 2. Twenty locations having negative environmental indices were considered to be low-yielding sites (LYS) and those with positive environmental indices, including one with a minimum negative deviation, were defined as high-yielding sites (HYS).

#### Spatial method and similarity measurement

The stability analysis method, based on principal coordinate analysis, proposed the following equation for measuring similarity between two genotypes,  $a$  and  $b$ , in a given environ-

**Table 1.** Varieties included in 1980 EVT

Variety code no.	Variety name	
1	San Andres	7721
2	Poza Rica	7921
3	Maracay	7921
4	Cotaxtla	7921
5	Cotaxtla	7822
6	Ilonga	7822
7	Across	7822
8	Los Diamantes	7823
9	Cali	7823
10	Across	7823
11	Poza Rica	7925
12	Maracay	7925
13	Cotaxtla	7925
14	San Andres	7925
15	Cuyuta	7929
16	Poza Rica	7929
17	Cotaxtla	7929
18	Sids	7929/1
19	Sids	7929
20	Maracay	7832
21	Across	7832
22	Sakha	7832
23	Gandajika	7832
24	Across	7843
25	Ejura	7843
26	Across	7622
27	Across	7729

**Table 2.** Classification of genotypes based on their regression slope ( $b_i$ ) in low yielding sites (LYS) and high yielding sites (HYS) (Verma et al. 1978)

$b_i$		
LYS	HYS	
< 1.0	< 1.0	Best for LYS
> 1.0	< 1.0	Best for LYS
< 1.0	= 1.0	Ideal
< 1.0	> 1.0	Ideal
> 1.0	> 1.0	Best for HYS

ment  $i$  (Westcott 1987):

$$S_i(a, b) = [H_i - (a_i + b_i)/2] / H_i - L_i,$$

where

$H_i$  = highest mean yield of a genotype in environment  $i$ ;  
 $L_i$  = lowest mean yield of a genotype in environment  $i$ ;  
 $a_i$  = mean yield of genotype  $a$  in environment  $i$ ; and  
 $b_i$  = mean yield of genotype  $b$  in environment  $i$ .

When more than one environment is considered, the similarity between genotypes  $a$  and  $b$  is defined as the average of  $S_i(a, b)$  across environments.

The similarity measured between any given pair of genotypes indicates the proximity of its average to  $H_i$ , and the dissimilarity  $[1 - S_i(a, b)] = [((a_i + b_i)/2) - L_i] / H_i - L_i$  indicates the proximity of its average to  $L_i$ . Consider, for example, four genotypes (1, 2, 3, and 4) ranked from lowest to highest as 2, 1, 3, and 4. The similarities between the six pairs of genotypes,

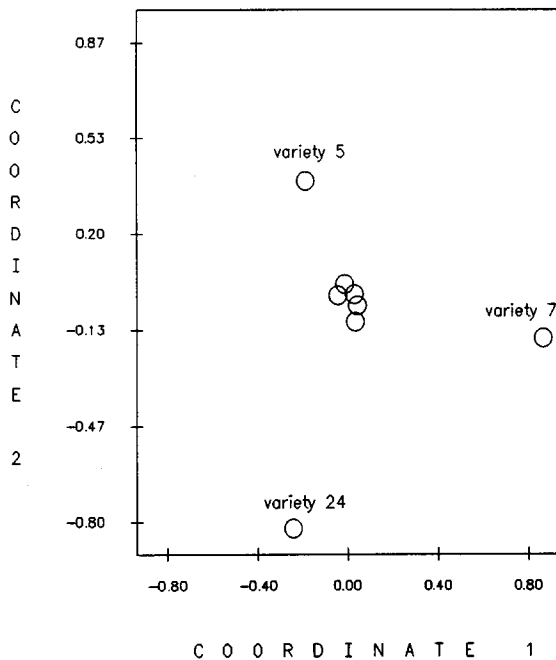


Fig. 1. Plot of the first two principal axes from a principal coordinate analysis of a set of 27 maize varieties in cycle H5

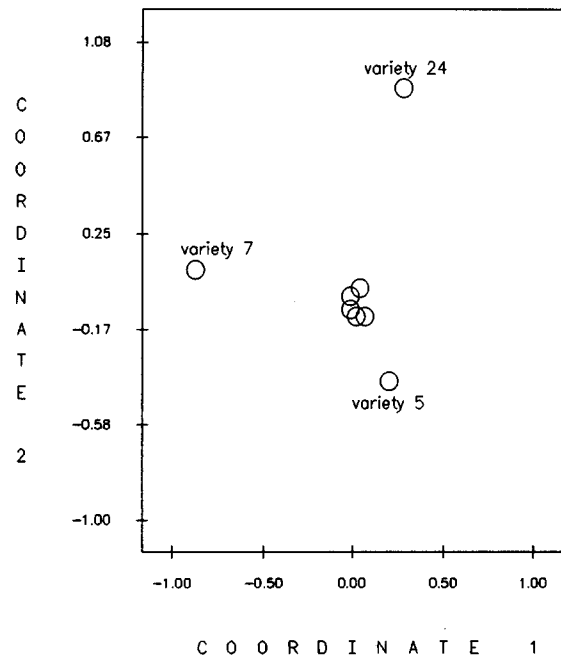


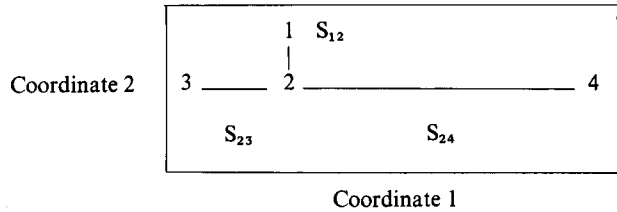
Fig. 2. Plot of the first two principal axes from a principal coordinate analysis of a set of 27 maize varieties in cycle H6

measured as the proximity of the average performance of each pair to H, are  $S_{12} > S_{23} > S_{13} > S_{24} > S_{14} > S_{34}$ ; their dissimilarities with respect to L are  $1 - S_{12} < 1 - S_{23} < 1 - S_{13} < 1 - S_{24} < 1 - S_{14} < 1 - S_{34}$ .

Smaller values for S indicate greater proximity to H (greater dissimilarity to L); higher values for S indicate greater proximity to L, and for the pair (2, 4) (L, H)  $S = (1 - S) = 1/2$ .

The analysis determines a point (genotype) from which all other genotypes radiate. This point, with maximum value for S, is the center of the diagram (see Westcott 1987, on minimum spanning tree). Therefore, genotypes with higher values for S are represented by points clustered near the center of the diagram and genotypes with smaller values for S are represented by points further away from the center.

A two-dimensional diagram produced by the principal coordinates analysis for the four genotypes given on the above example is as follows:



The distances between points represent the relationships between the corresponding points as given in the original similarity matrix. The proximity of genotypes 1, 3, and 4 to genotype 2 corresponds to their rank in performance (genotype 4 is represented by the more remote point, followed by genotype 3).

Excluding one or more items does not affect the relationship of the remaining points. For instance, if only genotypes 2, 3, and 4 are considered, the new similarity matrix is the same as before, but without the first column.

For the purposes of this study the sites were grouped based on their environmental indices; in each of the sub-groups, the sites were ranked in descending order according to the site means. The analysis of genotype performance was carried out in cycles, the first of which included only the lowest yielding site (cycle L1), the second the two lowest yielding sites (cycle L2), and so on. High-yielding sites were analyzed similarly, beginning with the highest yielding site (cycles H1, H2, etc.).

The more stable varieties, those that consistently showed above-average performance over consecutive analyses, were represented by the points that appeared furthest from the center of the diagram. Rather than include a large number of diagrams, the stability pattern of the varieties are described in words and only a sequence of five diagrams (Figs. 1-5), corresponding to cycles H5-H9, are presented.

**Results and discussion**

Site means for grain yield ranged from 5.04 to 9.21 Mg ha<sup>-1</sup> at the 17 highest yielding sites (HYS) and from 1.20 to 4.88 Mg ha<sup>-1</sup> at the 20 lowest yielding sites (LYS).

*Stability analysis of 17 HYS and 20 LYS*

*Spatial method.* The two best varieties over 17 high-yielding sites reported in Table 3, varieties 7 (6.87 Mg ha<sup>-1</sup>) and 5 (6.75 Mg ha<sup>-1</sup>), had higher mean yields and showed yield stability in the H cycles. The points representing those varieties were consistently farther than others from the center of the diagrams (Figs. 1-5). This trend corresponded to the excellent yield per-

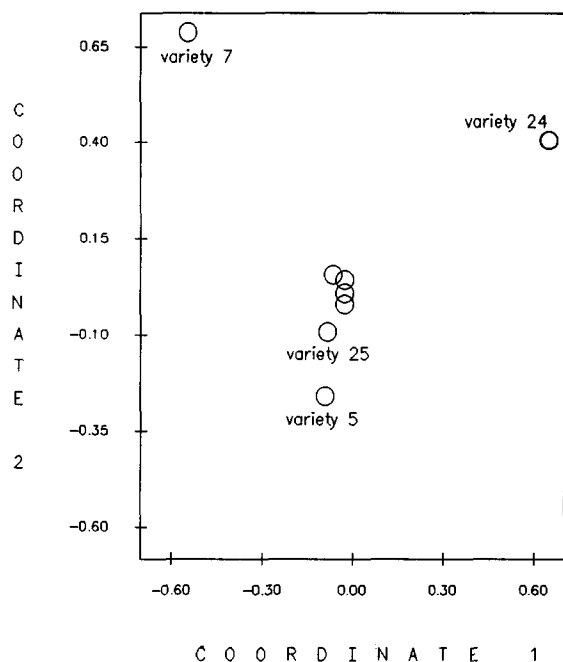


Fig. 3. Plot of the first two principal axes from a principal coordinate analysis of a set of 27 maize varieties in cycle H7

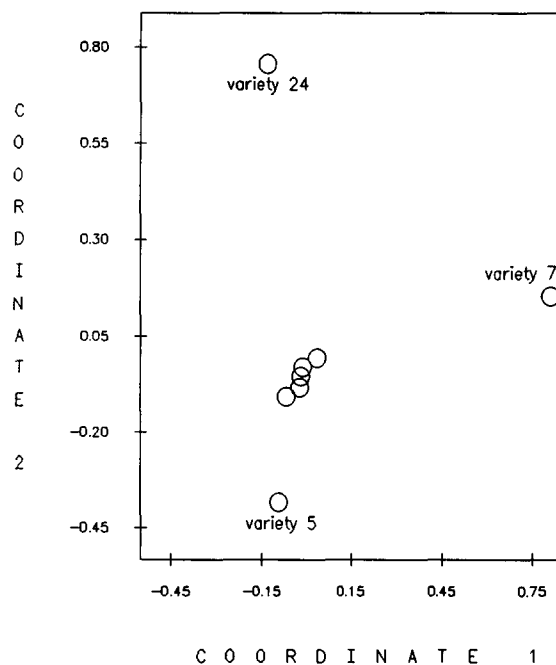


Fig. 5. Plot of the first two principal axes from a principal coordinate analysis of a set of 27 maize varieties in cycle H9

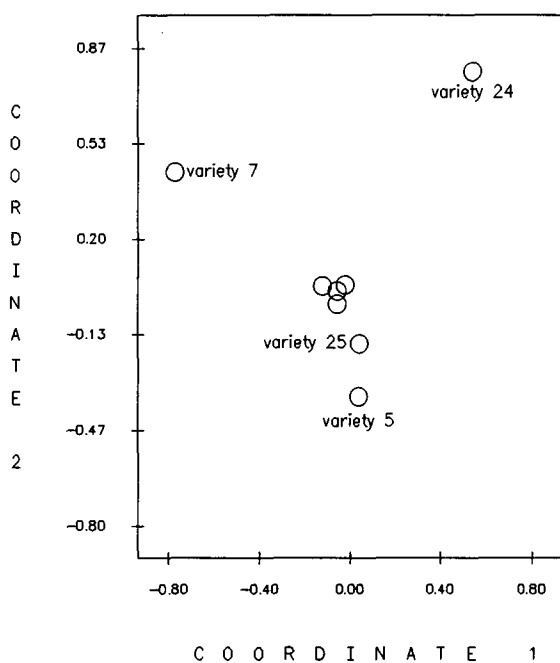


Fig. 4. Plot of the first two principal axes from a principal coordinate analysis of a set of 27 maize varieties in cycle H8

formance of those varieties at most of the HYS. Variety 24, which ranked third overall with an average yield of  $6.56 \text{ Mg ha}^{-1}$  (Table 3), yielded well at all but three sites and appeared closer to the center of the diagrams for cycles H10 to H17. In all diagrams, the changes in the positions of varieties from one cycle of analysis to

the next corresponded to variations between locations in the ranking of the varieties by mean yield.

The results obtained with the spatial method are useful for comparing the merits of different varieties, and indicate clearly which ones are capable of both high yield and yield stability across environments. In comparing variety 25 with varieties 5, 7, and 24, for example, the latter three were represented by remote points and yielded more than variety 25 at most locations. Scatter point diagrams related to the analyses over the seven and eight highest yielding sites (cycles H7 and H8, respectively, are shown in Figs. 3 and 4). Although variety 25 appeared apart from the center, it is less remote than varieties 5, 7 and 24. In summary, analysis of the 17 highest yielding sites indicates that varieties 5, 7, and 24 are the more stable.

The four highest yielding varieties over 20 low-yielding sites were varieties 7 ( $4.24 \text{ Mg ha}^{-1}$ ), 24 ( $4.15 \text{ Mg ha}^{-1}$ ), 5 ( $4.14 \text{ Mg ha}^{-1}$ ), and 15 ( $4.14 \text{ Mg ha}^{-1}$ ) (Table 3). Variety 7 performed well and is represented by outlying points in all the L cycles except L1 and L2. It was closely followed by variety 5, which did not appear in L1 and appeared close to the center in L2, L3, L10, L11, and L12. Variety 15 performed well in poor sites; it was not a remote point in L1 to L3 and was close to the center in L6, L14, and L16. Variety 5 yielded below the site mean at four sites, variety 7 was near or below the mean at three sites, and variety 15 performed below the average at seven sites. Varieties 2 and 6 were more stable, the former being good in L9

**Table 3.** Grain yield means (Mg ha<sup>-1</sup>) and regression coefficients ( $b_i$ ) of 27 varieties in 20 low yielding sites (LYS) and in 17 high yielding sites (HYS)

Variety no.	LYS		HYS	
	Mean	$b_i$	Mean	$b_i$
1	3.92	1.16	5.97	1.06
2	4.11	1.04	6.24	0.95
3	4.06	1.13*	6.45	1.00
4	3.94	0.99	6.46	1.00
5	4.14	1.02	6.75	1.10
6	4.13	1.03	6.44	1.03
7	4.24	1.00	6.87	1.08
8	3.88	0.84	6.06	0.78*
9	3.81	0.96	5.91	0.92+
10	3.88	1.01	6.05	0.92
11	3.70	0.94	6.19	1.15
12	3.64	0.91	5.67	1.03
13	3.42	0.81*	5.66	1.07
14	3.80	0.92	5.91	0.88++
15	4.14	1.08+	6.32	0.96
16	4.08	1.06	6.23	0.83*
17	3.95	0.88	6.21	0.97
18	4.06	1.07	6.47	1.06
19	4.00	1.11++	6.04	0.95
20	3.44	0.73**	5.77	0.87+
21	3.58	0.97	5.84	1.15+
22	3.48	0.93++	5.75	0.92
23	3.56	0.88++	5.81	0.96++
24	4.15	1.18++	6.56	1.24++
25	4.03	1.09++	6.41	1.10++
26	4.03	1.15	6.34	0.87
27	3.86	1.10+	6.18	1.15*
Mean	3.89		6.16	
SE	0.08		0.09	

\*. \*\*  $b_i$  significant at 5% and 1% levels, respectively

+. ++  $S^2_{di}$  significant at 5% and 1% levels, respectively

to L16, while the latter performed well in L1 to L5. Variety 24 was stable in cycles L10 to L15.

From the analysis of both sets of sites, it seems that varieties 5 and 7 (selected from population 22 in 1978) have relatively good yields, maintained their yield stability at low-yielding sites, and responded well to more favorable sites. However, variety 24 (formed from population 43 during 1978 on the basis of across-site yield data) performed very well and maintained its yield stability only at high-yielding sites.

This method of stability analysis has been applied extensively to varieties derived from several CIMMYT maize populations that were evaluated in international trials from 1979 to 1983 in numerous countries (Crossa et al. 1987; Westcott 1987). The results provide evidence that populations 22 and 43 produced the more stable varieties. Variety 7 also consistently performed well at low- and high-yielding sites in an EVT conducted during 1981.

These results agree with those of Paliwal and Sprague (1981) that variety 7 has shown broad environmental adaptation. Those authors also noted that population 43 is an excellent source of stable varieties that have performed well in Central America and Africa.

*Regression analysis.* Mean grain yields and regression slopes of all varieties tested in each of the two subsets of sites are listed in Table 3. According to the  $b$  values, neither variety 5 nor variety 7 approached the ideal genotype, though both have increased slopes in favorable sites. Variety 13 can be considered ideal, judging from its slope, but it has the lowest yield performance in LYS and HYS. Varieties 15 and 26 can be regarded as the best for poor sites, even though their slopes are not significantly different from one and the former had a significant deviation from regression in LYS. Varieties 8 and 20 can also be classified as good for LYS based on the  $b$  values, but they yielded below average in LYS and HYS. Variety 24 is the best for HYS judging from its slope and mean yield; however, its  $S^2_{di}$  was highly significant in both LYS and HYS. Variety 27 can be regarded as good for favorable sites, but it only showed an average mean yield in LYS and HYS.

The results of regression analysis agree only partially with those obtained using the spatial method. The regression slopes of varieties 5 and 7 do not clearly reflect their performance in poor and favorable sites. For some varieties, it seems to be difficult to reach a fair compromise between the mean, the slope, and the deviation from regression that will allow the breeder to make a correct decision as to the superiority of the varieties. Lin et al. (1986) suggested the main reason for the difficulty in trying to reconcile these stability parameters in a unified conclusion: even though the genotype's response to environments is multivariate, the regression approach tries to transform it into a univariate problem by means of a stability index.

#### *Stability analysis of 16 HYS and 19 LYS*

One aspect of this study was to determine the effect of excluding either extremely good or extremely poor sites on the results obtained with the two stability analysis methods under consideration.

*Spatial method.* Stability analysis performed on 16 HYS indicated that varieties 5, 7, and 24 were represented by the most remote points in most of the H cycles, although variety 24 did not appear in H2 and H3 and was near the center of the diagram in H9 to H16. Varieties 4, 6, and 18 were clustered (coinciding with variety 24) near the center in cycles H10 to H16. But

while variety 4 was represented by an outlying point in H1 and H2, variety 18 appeared in H1 to H4.

When the lowest yielding site was excluded, varieties 7 and 15 showed a clear pattern of stability over all the L cycles. Variety 5 did well because it appeared near the center in L2 and L8 to L15. Varieties 2 and 24 were outlying points only in L8 to L13; from L14 to L19 they tended to be grouped closer to the center of the diagrams.

It can be concluded that those varieties found to be the highest yielding and most stable when all sites were analyzed were also found to be high yielding and stable when the highest and the lowest yielding sites were excluded from the analysis.

*Regression analysis.* Results of regression analysis, with extreme sites excluded, are listed in Table 4.

The magnitude of the change in the regression slope of an entry, when the worst site was not included, is inversely related to the magnitude of its change in rank. For example, variety 25 ranked 4th at the lowest yielding site and 19th at the next lowest yielding site. It showed  $b=1.09$  for the analysis of the 20 LYS and  $b=1.28$  when the poorest site was omitted. The better performance of variety 24 in the second lowest yielding site (ranked 9th), compared with its performance in the worst site (ranked 27th), was reflected in its  $b$  value when 19 LYS were analyzed ( $b=1.02$  vs  $b=1.18$ ). Variety 15 ranked 25th at the lowest yielding site and 1st at the next lowest yielding site. When the worst site was omitted, the new regression line for variety 15 became less ( $b=0.88$  vs  $b=1.08$ ), and its deviation from regression was not significantly different from zero. Variety 15 can, therefore, be considered good for poor sites. Variety 5 ranked similarly in the two lowest yielding sites; its slope, when the worst site was omitted, remained unchanged.

When the highest yielding site was omitted, variety 5 (with a significant slope of 1.23) appeared more responsive to favorable environmental conditions, and variety 7 had new  $b$  values of 0.93 and 1.01 for LYS and HYS, respectively, which are close to being ideal. The new  $b$  values for varieties 8 and 27 when the best site was not included are 0.84 and 1.16, respectively. Varieties 5 and 7 are close to being considered ideal, variety 15 can be selected for poor environments. Variety 24, judged by its slope, is no longer the best for HYS. It is remarkable how one extreme data point out of 20 or 17 influenced the estimates of stability parameters for some varieties and masked the good performance that some of them gave in most other environments.

These results agree with those of Hill and Baylor (1983), who indicated that low site mean had a great

**Table 4.** Grain yield means ( $\text{Mg ha}^{-1}$ ) and regression coefficients ( $b_i$ ) of 27 varieties in 19 low yielding sites (LYS) and in 16 high yielding sites (HYS)

Variety no.	LYS		HYS	
	Mean	$b_i$	Mean	$b_i$
1	4.09	1.15	5.78	1.06
2	4.28	0.89	6.08	0.96
3	4.22	1.17*	6.25	0.93
4	4.08	1.04	6.30	1.09
5	4.29	1.02	6.59	1.23*
6	4.27	1.06	6.28	1.12
7	4.39	0.93	6.66	1.01
8	3.99	0.87	5.93	0.84
9	3.95	0.93	5.73	0.86 <sup>+</sup>
10	4.01	1.09	5.88	0.92
11	3.84	0.88	5.99	1.20
12	3.77	0.97	5.44	0.89
13	3.55	0.71*	5.46	1.05
14	3.94	0.80	5.72	0.73 <sup>+</sup>
15	4.31	0.88	6.12	0.85
16	4.23	1.08	6.06	0.77*
17	4.07	0.99	6.03	0.91
18	4.20	1.17	6.31	1.17
19	4.14	1.19 <sup>++</sup>	5.88	1.01
20	3.55	0.65*	5.59	0.81 <sup>++</sup>
21	3.71	0.99	5.63	1.12 <sup>+</sup>
22	3.61	0.98 <sup>++</sup>	5.59	0.96
23	3.66	1.03 <sup>++</sup>	5.65	1.00 <sup>++</sup>
24	4.33	1.02 <sup>++</sup>	6.32	1.19 <sup>++</sup>
25	4.17	1.28 <sup>++</sup>	6.23	1.19 <sup>++</sup>
26	4.19	1.16	6.20	0.94
27	4.01	1.10 <sup>+</sup>	5.98	1.16
Mean	4.03		5.99	
SE	0.08		0.09	

\*  $b_i$  significant at 5%

+ <sup>++</sup>  $S^2_{di}$  significant at 5% and 1% levels, respectively

influence on the estimate of the regression coefficients. They concluded that regression analysis had to be used with caution when one of the environments was atypical. Exclusion of those sites evidently had no influence, however, on the ability of the spatial method to detect high-yielding, stable varieties.

#### *Analysis of a subset of seven varieties*

In analyzing a subset of entries, one would expect to obtain different stability parameters from those determined for the complete set of entries because: (1) regression coefficients are calculated on the basis of an environmental index (the difference between the overall and site means), which depends on the set of entries under consideration, and (2) deviations from regression are not independent from regression coefficients (Hardwick and Wood 1972).

**Table 5.** Grain yield means ( $\text{Mg ha}^{-1}$ ) and regression coefficients ( $b_i$ ) of 7 varieties in 20 low yielding sites (LYS) and in 17 high yielding sites (HYS)

Variety no.	LYS		HYS	
	Mean	$b_i$	Mean	$b_i$
7	4.23	0.96 <sup>++</sup>	6.87	1.04
14	3.80	0.87 <sup>+</sup>	5.91	0.86 <sup>+</sup>
19	3.98	1.08 <sup>++</sup>	6.45	0.90
22	3.48	0.93 <sup>+</sup>	5.75	0.92
23	3.55	0.90 <sup>++</sup>	5.80	0.94 <sup>++</sup>
24	4.14	1.18 <sup>++</sup>	6.56	1.24 <sup>++</sup>
25	4.03	1.06 <sup>++</sup>	6.41	1.09 <sup>+</sup>
Mean	3.89		6.20	
SE	0.07		0.09	

<sup>+</sup>, <sup>++</sup>  $S^2_{di}$  Significant at 5% and 1% levels, respectively

It has been shown that the stability of one particular genotype evaluated by the regression analysis method depends on the mean performance of the group with which that entry is being compared (Knight 1970; Witcombe and Wittington 1971; Mead et al. 1986; Lin et al. 1986). The final part of this study attempts to determine whether consideration of an isolated subset of entries has an equally great effect on results obtained with the two stability analysis methods. The varieties were selected based upon the magnitude of deviation from regression. The subset comprises variety 7 with low  $S^2_{di}$  in low and high yielding sites and six varieties (14, 19, 22, 23, 24, and 25) with relatively high values of  $S^2_{di}$  in LYS or HYS or in both.

*Spatial method.* Varieties 7 and 24 were the top performers at all high-yielding sites and showed a clear pattern of stability in all the H cycles; they were closely followed by variety 25. Variety 7 performed best over the 20 LYS. It was consistently the furthest point from the center of the diagrams in all L cycles. Variety 19 performed well in general, although it appeared closer to the center in L12 to L20 and did not appear at all in L1. Variety 24 was clearly an outlying point in L8 to L20. While variety 14 showed an erratic stability pattern in L cycles, variety 25 performed well in most of them.

As was anticipated, regardless of the subset of genotypes to which varieties 7 and 24 are being compared, their stability pattern was accurately detected by the spatial method and clearly outlined in diagrams. It seems that considering this isolated subset of varieties has no effect on the results obtained with the spatial method. This feature of the spatial method is particularly useful for comparing the stability of varieties within particular groups that include varieties derived

from populations having different yield potential. A logical approach would be to compare yield stability within each group of varieties formed from the same population.

*Regression analysis.* None of the slope values was significantly different from one (Table 5). While variety 7 can be regarded as ideal, judging from its slope and mean yield, it drastically changed its  $S^2_{di}$  value in LYS; when only seven varieties were included in the regression analysis the deviation from regression of variety 7 was highly significantly different from zero. Similar results were reported by Easton and Clements (1973), who confirmed that the yield stability of one entry varied according to the average response of the rest of the group.

## Conclusion

For the varieties and sites analyzed in this study, the spatial method gives more satisfactory results than regression analysis in detecting genotypes that perform well and remain stable under different environmental conditions. The main advantages of the spatial method are as follows: (1) the method is highly trustworthy when used to analyze a data set that includes results from a few extremely low- or high-yielding locations; (2) the method overcomes the dependency problem present in the regression analysis when a subset of genotypes is analyzed separately from the entire group; (3) it avoids the difficulty that arises when regression parameters have to be unified in one decision; (4) it is simple to identify stable varieties from the sequence of graphic displays generated for each cycle of analysis; and (5) the approach is model-free (no assumptions regarding the distribution of the variables are needed) and can be applied without a large set of environments.

The first two of those five advantages should be of interest to breeding programs in which trials are grown under different environmental conditions or in which breeders want to compare stability within a specific subset of genotypes that for some reason have been grouped.

However, when comparing varieties in a large number of very similar environments, regression analysis might be adequate in detecting stable varieties. Further research is needed to compare the spatial method with other multivariate techniques.

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